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An Integrated Antenna Mast for Shipboard Applications

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CONTENTS

1.0 INTRODUCTION

Antennas provide essential data links between different communication systems. Depending on the frequency of operation, applications may include ship-to-shore amphibious landing, ship-to-air communications, and ship-to-ship tactical maneuver operations. Currently, the Navy uses several frequency bands for communications. These bands include HF, VHF, UHF, and L-band. The advantage of using a higher frequency for communications is the short wavelength, which allows a smaller and lighter antenna. Additionally, a shorter wavelength will make the antenna design simpler to implement and easier to install on the ship’s topside (usually on the mast platform or yardarm). Although numerous antenna configurations are available for shipboard communication antennas, the most popular configuration is the dipole. In practice, there are many forms of dipole. One reason for this is stringent bandwidth requirements, especially for naval shipboard fixed communication antennas where the objective is to achieve omnidirectional coverage independent of the ship’s heading.

Recent advances in frequency-selective surface (FSS) radome technology have shown that this type of radome can play a key role in low observable (LO) applications (reference 1). In this type of radome, the FSS elements, which are embedded inside the supporting structure, are used to control the frequency response. The supporting structure can be a combination of a composite layer and a collection of FSS elements, which can be in slots or wire segments depending on the frequency response, bandwidth, polarization, and out-of-band rejection requirements. The major difference between a conventional radome and an FSS radome is that the latter can have the true characteristics of a filter. Additionally, by taking advantage of the rejection level outside the designated bandwidth, the radome can be made to form an LO through object shaping.

The Navy is also exploring the concept of using a shared aperture for communication system applications. Sharing of antennas among systems is simply an extrapolation of existing developments aimed at sharing communication systems among users. Eventually, it may be possible to support dissimilar radiating systems with a single antenna. Therefore, one design goal under the composite mast project is to develop a common antenna that can be shared by different communication systems. The two antenna systems under consideration are the AS-3020/SR and the AS-3221/SR. The AS-3020/SR antenna system is used to transmit and receive ship-to-ship and ship-to-air signals over the VHF, UHF, and L-band channels. The antenna is a stacked collinear structure of four independent omnidirectional dipole radiators. The first and the fourth antenna subassemblies are for the UHF (225 to 400 MHz) band. The second subassembly is for the VHF (115 to 162 MHz), and the third is an identification, friend or foe (IFF) array for the L-band (1000 to 1150 MHz). The requirements for the AS-3021/SR antenna system are very similar to the UHF portion of the AS-3020/SR except that the antenna gain and the channel number are different.

The objective of this antenna task is to integrate the AS-3020/SR and AS-3221/SR into one antenna system to reduce the number of antennas on the topside of the ship and, at the same time, use the FSS radome to develop a radar cross section (RCS) signature-controlled communication antenna. This report describes the concept of an RCS signature-controlled communication antenna. The AS-3020/SR and AS-3221/SR are combined to form one antenna. The new antenna arrangement has a radome made of FSS elements to control the frequency response. The shape of the radome was optimized to obtain a minimal RCS. One of the performance goals for the RCS signature-controlled radome design is to obtain maximum out-of-band rejection without compromising the in-band insertion loss. The system configuration of the integrated antenna is described in section 2.0. Numerical data on the radome performance are also presented. Conclusions and recommendations for future studies are presented in section 3.0.

2.0 INTEGRATED ANTENNA MAST ARCHITECTURE

2.1 ANTENNA SPECIFICATIONS

This section describes the system configuration of the integrated antenna; following are the electrical specifications for the new integrated polemast antenna.

Antenna Element #1:

Frequency:	225 to 400 MHz
Power Handling:	1000-W average
Polarization:	95% of radiated energy shall be vertically polarized
Gain:	Maximum gain within the beam limits is +1.0 dBi or greater over the 225- to 300-MHz frequency range and is +1.5 dBi over the 300- to 400-MHz frequency range. The minimum gain within the beam limits is –1.5 dBi or greater over the 225- to 400-MHz frequency range.
Input impedance:	50 ohms
Maximum VSWR:	2.0:1 or less over at least 50% of the specified frequency range and is 2.2:1 maximum at any frequency in the range
Circularity of pattern:	Horizontal radiation pattern omnidirectional to within $\pm$3/4 dB
Operating temperature:	–40°C to 65°C

Antenna Element #2:

Frequency:	1000 to 1150 MHz
Power Handling:	500-W average
Polarization:	95% of radiated energy shall be vertically polarized
Gain:	Maximum gain within the beam limits is +4.0 dBi or greater. The minimum gain within the beam limits is 0 dBi or greater.
Input impedance:	50 ohms
Maximum VSWR:	Less than 2.0:1 over the specified frequency range
Circularity of pattern:	Horizontal radiation pattern omnidirectional to within $\pm$3/4 dB
Operating temperature:	–40°C to 65°C

Antenna Element #3:

Frequency:	225 to 400 MHz
Power Handling:	1000-W average
Polarization:	95% of radiated energy shall be vertically polarized
Gain:	Maximum gain within the beam limits is +1.0 dBi or greater over the 225- to 300-MHz frequency range and is +1.5 dBi over the 300- to 400-MHz frequency range. The minimum gain within the beam limits is –1.5 dBi or greater over the 225- to 400-MHz frequency range.
Input impedance:	50 ohms
Maximum VSWR:	2.0:1 or less over at least 50% of the specified fre– quency range and is 2.2:1 maximum at any frequency in the range
Circularity of pattern:	Horizontal radiation pattern omnidirectional to within ±3/4 dB
Operating temperature:	–40°C to 65°C

Antenna Element #4:

Frequency:	115 to 162 MHz
Power Handling:	100-W average
Polarization:	95% of radiated energy shall be vertically polarized
Gain:	Maximum gain within the beam limits is +1.0 dBi or greater. The minimum gain within the beam limits is –20 dBi or greater.
Input impedance:	50 ohms
Maximum VSWR:	Less than 2.0:1 over the specified frequency range
Circularity of pattern:	Horizontal radiation pattern omnidirectional to within ±3/4 dB
Operating temperature:	–40°C to 65°C

Antenna Element #5:

Frequency:	225 to 400 MHz
Power Handling:	1000-W average
Polarization:	95% of radiated energy shall be vertically polarized
Gain:	Minimum 2.5 dB above an isotropic source
Input impedance:	50 ohms
Maximum VSWR:	2.0:1 or less over at least 50% of the specified frequency range and is 2.2:1 maximum at any frequency in the range
Circularity of pattern:	Horizontal radiation pattern omnidirectional to within ±3/4 dB
Operating temperature:	–40°C to 65°C

Antenna Element #6:

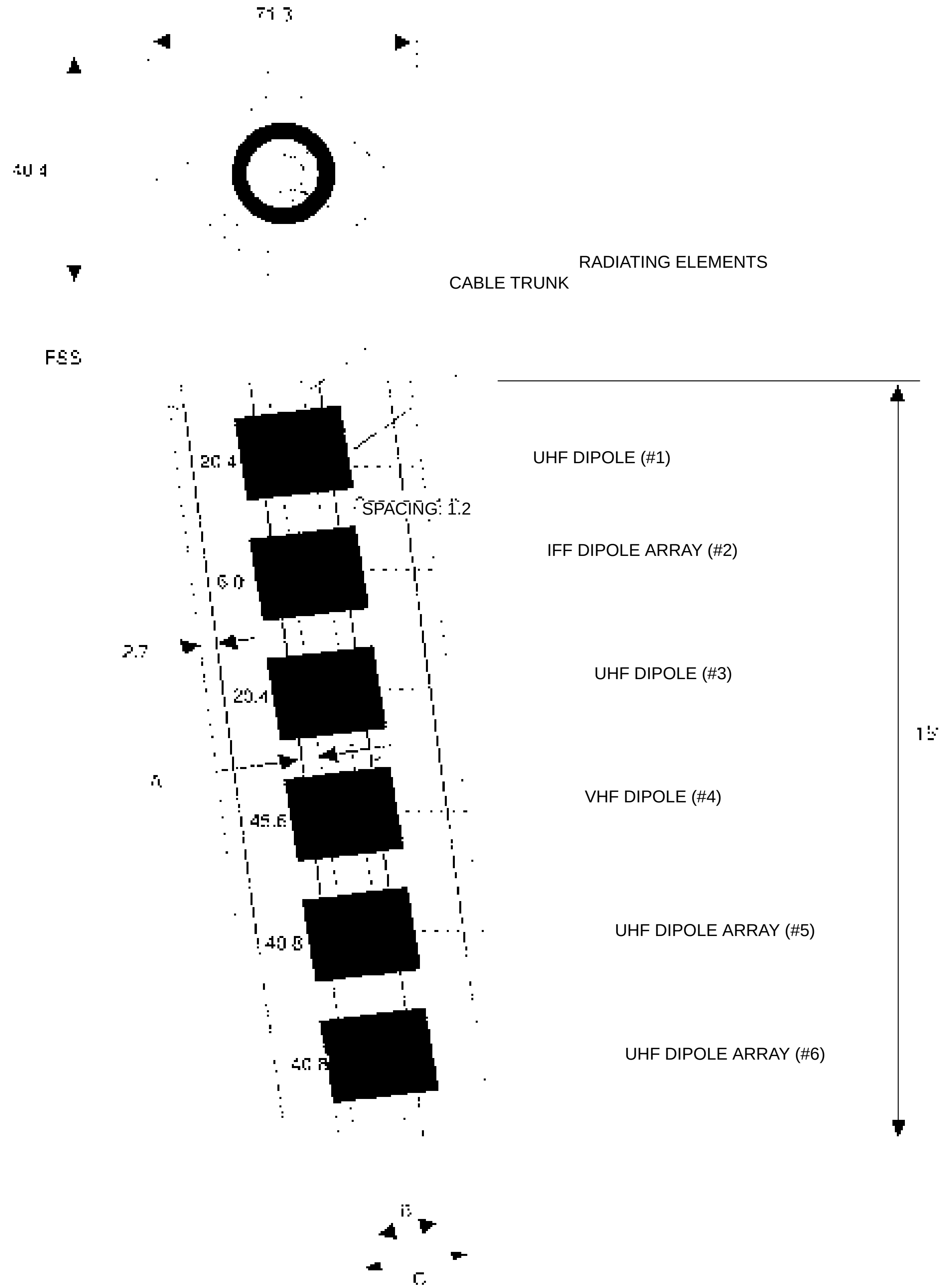
Frequency:	225 to 400 MHz
Power Handling:	1000-W average
Polarization:	95% of radiated energy shall be vertically polarized
Gain:	Minimum 2.5 dB above an isotropic source
Input impedance:	50 ohms
Maximum VSWR:	2.0:1 or less over at least 50% of the specified frequency range and is 2.2:1 maximum at any frequency in the range
Circularity of pattern:	Horizontal radiation pattern omnidirectional to within $\pm$3/4 dB
Operating temperature:	–40°C to 65°C

Note (applies to all elements): Isolation between frequency bands, at least 20 dB.

2.2 SYSTEM CONCEPT

Figure 1 shows the integrated antenna assembly with radome. The antenna is about 15 feet long and is positioned between the remote optical sight (ROS) and the TACAN antenna. The radome, which is an integral part of the antenna, has a diamond-shaped cross section 71.3 inches long and 40.4 inches wide. The dipole antenna elements are built around the circumference of the cable trunk, which structurally supports the antenna. Although the radiating elements are separated about 1.2 inches, radiating elements have been arranged to achieve maximum isolation of the VHF, UHF, and IFF bands. The metal cable trunk is hollow with an inside diameter of about 13 inches, allowing space for cables to feed the integrated polemast antenna and other structures above. The integrated antenna assembly has six independent channels that cover the VHF, UHF, and IFF bands. The lower two channels cover the UHF band, and the upper four channels cover the VHF, UHF, and IFF bands. The difference between the lower and upper UHF channels is the gain. All antenna elements are stacked collinearly to produce omnidirectional radiation patterns.

To produce an RCS signature-controlled polemast antenna, the radiating elements must be enclosed by a signature-controlled radome. At the operating frequency, the radome is transparent, allowing the energy through with very little or no loss, distortion, or change in antenna radiation patterns. Outside the designated bandwidth, the radome will appear to be reflective such that no RF energy can penetrate; therefore, shaping can be used to control the RCS profile. The shape of the antenna structure plays a very important role in the RCS profile outcome. Figures 2 and 3 show eight candidate shapes and their corresponding RCS profiles. These shapes include the vertical diamond, slanted diamond, vertical hex, slanted hex, vertical cylinder, slanted cylinder, cone, and hex cone. Depending on the configuration, the RCS profile can be either lower or higher than 0 dBsm. The calculations show that the slanted diamond shape gives the best RCS performance. Note that the polemast antenna is tilted by 10 degrees from the vertical position to achieve its best signature profile.



NOTE: All dimensions are in inches.

Figure 1. Integrated antenna assembly.

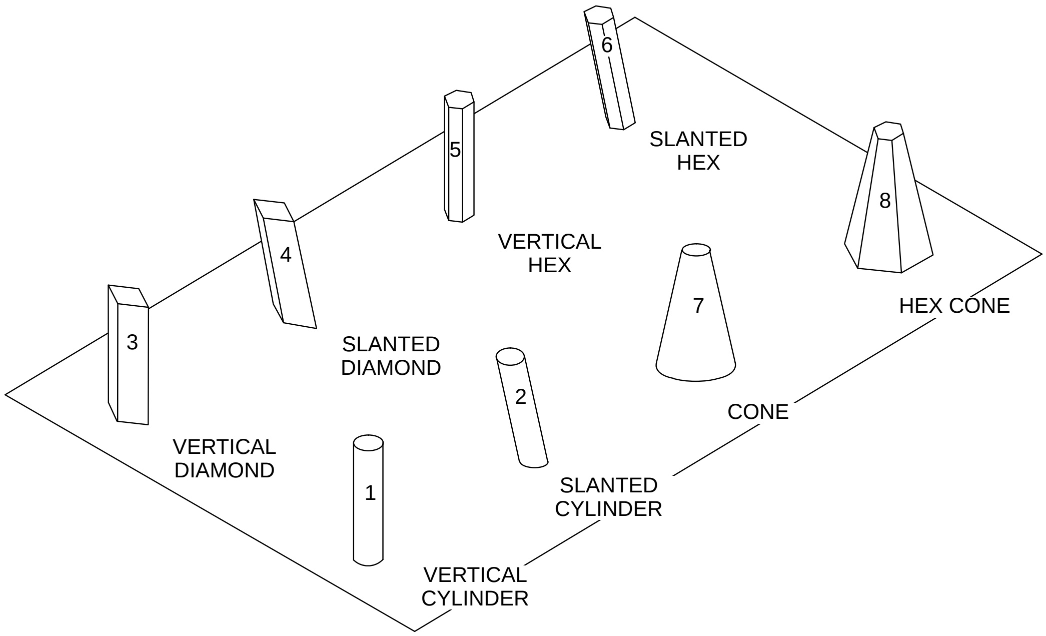


Figure 2. Candidate shapes for integrated antenna mast.

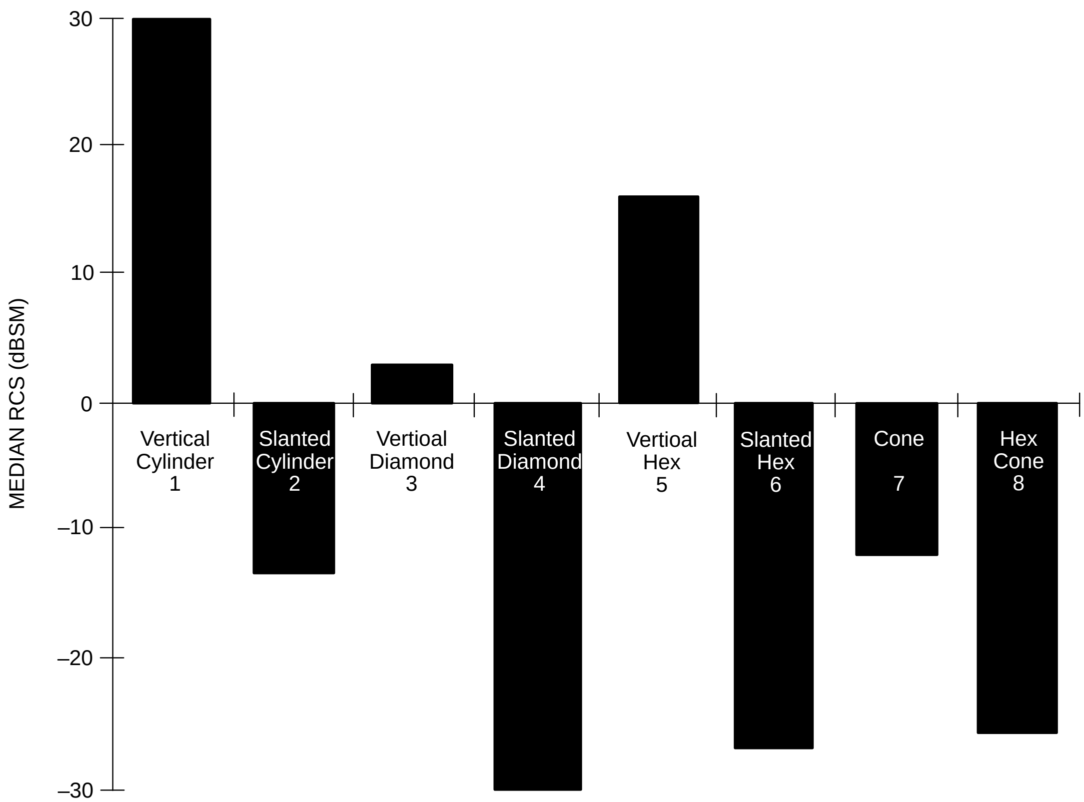


Figure 3. RCS of candidate shapes for integrated antenna mast.

2.3 FREQUENCY-SELECTIVE SURFACE RADOME

Figure 4 shows the geometry of a typical FSS radome. The radome is bounded by semi-infinite half spaces on the left and on the right, and the medium of each layer is assumed to be isotropic and homogenous. Generally, the scattered field produced at point $\vec{R}^{(n)}$ by an array of wire segments embedded in a stratified structure is given by:

$$\vec{E}(\vec{R}^{(n)}) = \frac{-I^{n'}}{2D_x D_z} \sum_k \sum_n \frac{e^{-j\beta m'(\hat{y}b_{m'} - \vec{R}^{(n')}) \cdot r_{m'}} e^{-j\beta m(\vec{R}^{(n)} - \hat{y}b_{m-1}) \cdot r_m}}{r_{my}}$$
$$\times \left({}_{\perp}P_{m'}^{(n')} \, {}_{\perp}T_{n',n}^{ee} + {}_{//}P_{m'}^{(n')} \, {}_{//}T_{n',n}^{ee} \right) \phi_{m'+1,\, m-1} \tag{1}$$

with

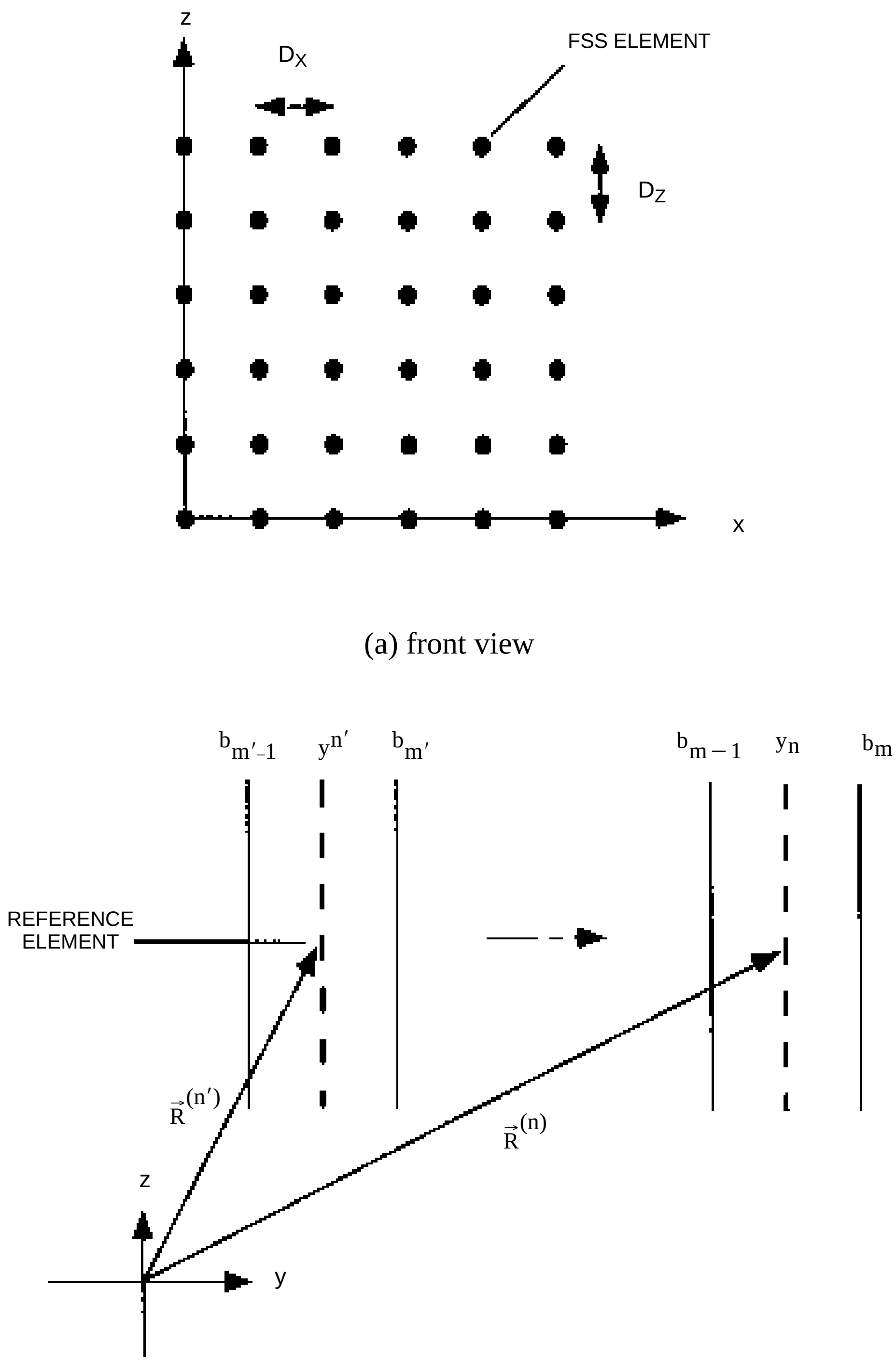
$$\phi_{m',\,m} = \prod_{i=m'}^{m} \phi_i \tag{2}$$

where the array is located in the plane $y^{n'}$ in slab m', and the field point $\vec{E}(\vec{R}^{(n)})$ is located in the plane y^n in slab m. Parameters D_x and D_z are the spacings between array segments along the x-direction and z-direction respectively, I is the current distribution along the wire segment, and P is the pattern factor. The term $T_{n',n}^{ee}$ represents the factor that accounts for all of the multipaths within the stratified structure, and it is given by the following expression:

$${}_{\perp}T_{n',n}^{ee} = {}_{\perp}T_{m',m} \frac{\left[1 + {}_{\perp}\Gamma_{m',m'-1} e^{-j2\beta_{m'}(y^{(n')} - b_{m'-1}) r_{m'y}}\right]\left[1 + {}_{\perp}\Gamma_{m,m+1} e^{-j2\beta_m(b_m - y^{(n)}) r_{my}}\right]}{1 - {}_{\perp}\Gamma_{m',m'-1} \, {}_{\perp}\Gamma_{m',m'+1} \phi_{m'}^2} \tag{3}$$

$${}_{//}T_{n',n}^{ee} = \frac{r_{m'y}}{r_{my}} \, {}_{//}T_{m',m} \frac{\left[1 + {}_{//}\Gamma_{m',m'-1} e^{-j2\beta_{m'}(y^{(n')} - b_{m'-1}) r_{m'y}}\right]\left[1 + {}_{//}\Gamma_{m,m+1} e^{-j2\beta_m(b_m - y^{(n)}) r_{my}}\right]}{1 - {}_{//}\Gamma_{m',m'-1} \, {}_{//}\Gamma_{m',m'+1} \phi_{m'}^2} \tag{4}$$

where T denotes the transmission coefficient and Γ represents the reflection coefficient. Note that the above formulation is strictly intended for a structure that has a single layer of FSS wire segments. For a structure that has an array of slots, duality and equivalence principles can be used to formulate the scattered field. Using the equivalence principle, the scattering from a slot in a ground plane can be represented by two equal magnetic currents. The end result is that the system of equations represents an admittance matrix instead of an impedance matrix. When the radome is composed of slots and wire segments, the system matrix will have impedances, admittances, current gains, and voltage gains. A more complete theory on FSS radomes may be found in reference 2.



(a) front view

(b) side view

Figure 4. Geometry of a typical FSS radome.

Figure 5 shows the side view of the actual FSS radome. The two outer layers are 0.30 inch thick and are made out of precured E-glass composite material with a dielectric constant of 4.5. The skins are neccessary to prevent possible damages to the radome's inner structure. The honeycomb layers are 1.575 and 0.9843 inches thick and are embedded between the skins. The FSS subassemblies are positioned between the honeycomb layers. Each FSS subassembly is basically a circuit board with FSS elements printed on one side of the FR4 substrate. The overall thickness of the radome is 2.70 inches.

Figures 6a, 6b, and 6c show the configuration of the FSS elements. The elements are tripoles to accommodate the circular polarization requirements. The radome has a low-pass frequency response that allows signals below the radome cutoff frequency through but rejects all other unwanted signals outside the designated bandwidth. Note that the radome surface appears to be reflective outside the designated bandwidth. In this design, there are three different sets, or subassemblies, of FSS elements. In the first subassembly (figure 6a), the FSS elements are separated by 267 mils in the x-direction and 309 mils in the y-direction. Each element is 36 mils wide, with a corresponding length (one arm) of 270 mils. The second FSS subassembly (figure 6b) is very similar to the first, except that the elements are separated by 188 mils in the x-direction and 217 mils in the y-direction, and each element is 25 mils wide and 190 mils long. The third FSS subassembly (figure 6c) is slightly different from the previous two. The anchors are designed along with the tripoles to enhance the out-of-band rejection level. The anchor is 8 mils wide and 35 mils long. The tripoles are 8 mils wide, 65 mils long, and are separated by 70 mils in the x-direction and 81 mils in the y-direction.

Figures 7a and 7b show the performance of the radome. The data are computed from 200 MHz to 18 GHz, with the transmission loss expressed in term of dB. As expected, a low-pass response is observed with an in-band insertion loss of 0.17 dB at VHF frequency. At UHF frequency, the insertion loss is about 0.4 dB. Moving up into the L-band, the insertion loss is also about 0.4 dB over the designated bandwidth. The out-of-band performance of the radome is excellent, with a typical rejection level of about 20 dB over the frequency range from 5 GHz to 18 GHz. Note that the data for both polarizations are plotted in figure 7 with a solid line representing the vertical polarization and a dashed line corresponding to the horizontal polarization. The frequency response for both polarizations is very similar; this is expected because unpolarized elements are used in the design. It is also important to point out that all computed data are for the 10-degree tilted case.

2.4 RADIATING ELEMENTS

This section defines the configuration for the radiating elements. As mentioned before, the integrated antenna has six independent channels that cover the VHF, UHF, and L-bands. Figure 8 shows the most promising candidate for the VHF and UHF radiators. The structure consists of four broadband radiating dipoles positioned equidistant from the center of the cable trunk and equally spaced from each other. Individual elements are fed in phase to provide an omnidirectional coverage over the designated bandwidth. The impedance matching transformers and feedlines are likely to be integrated with the antenna supporting framework. The impedance matching method is to first combine the two elements into a pair, and then combine the two pairs into a single feeding input.

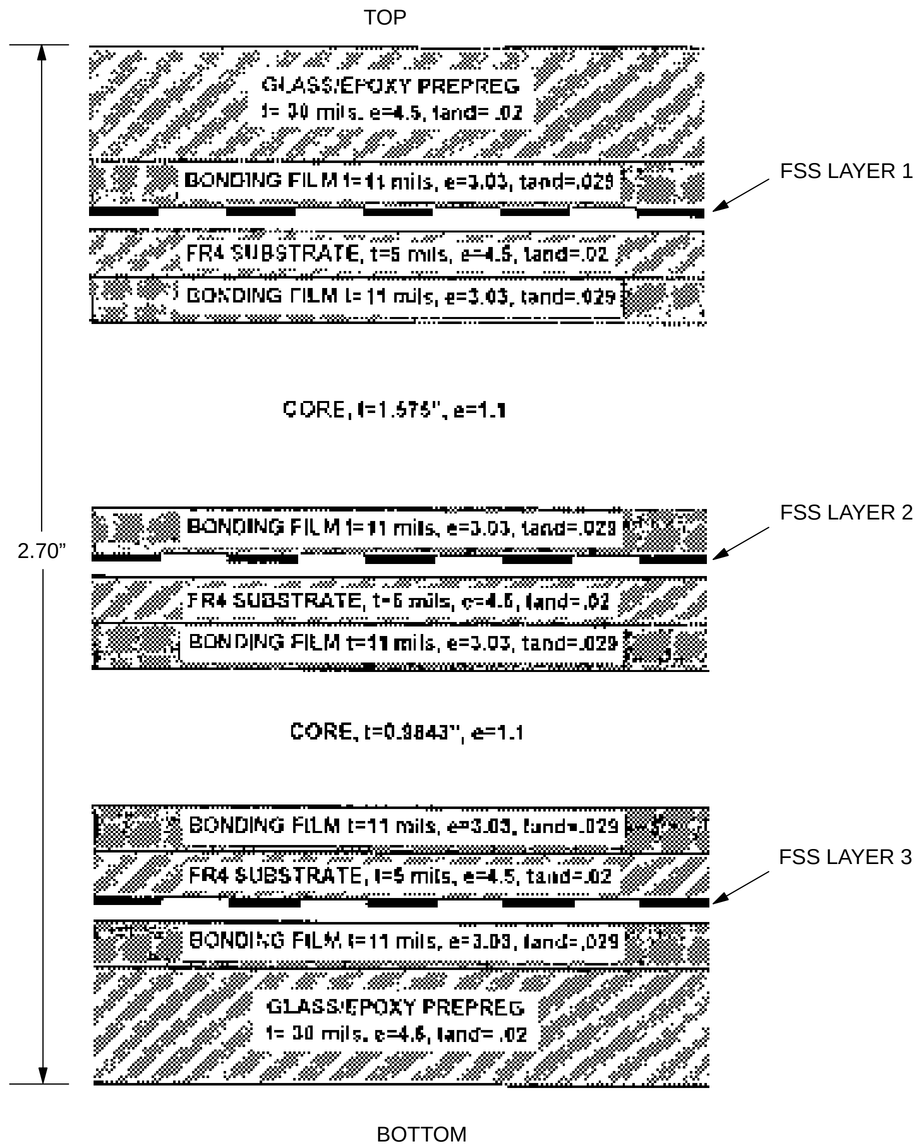
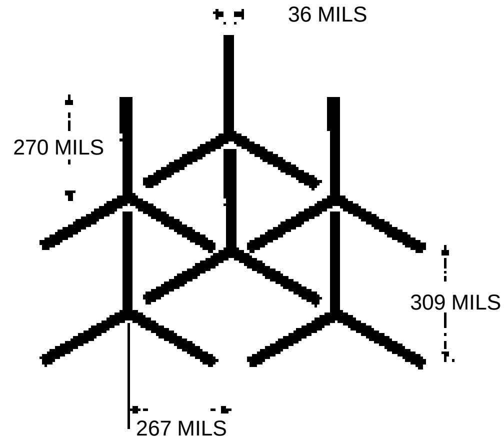
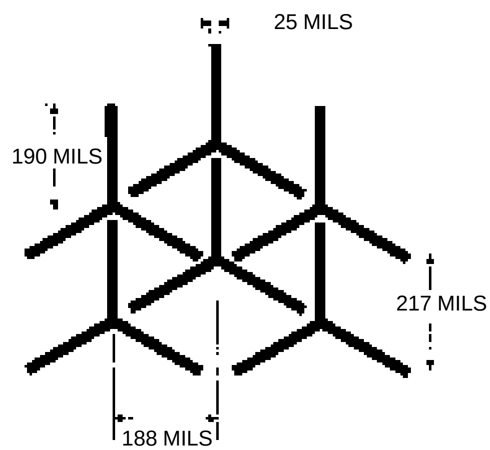


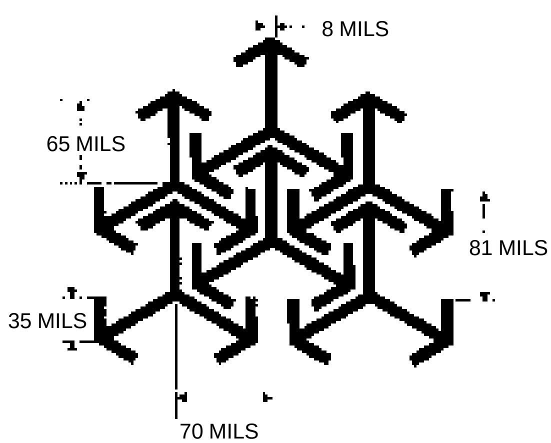
Figure 5. Side view of actual FSS radome.



(a) element configuration for first FSS layer

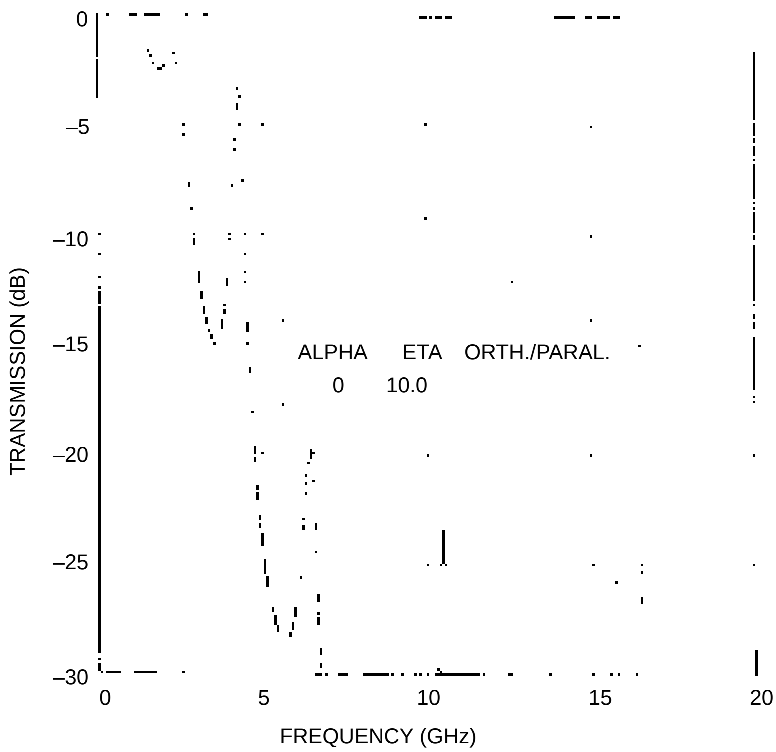


(b) element configuration for second FSS layer

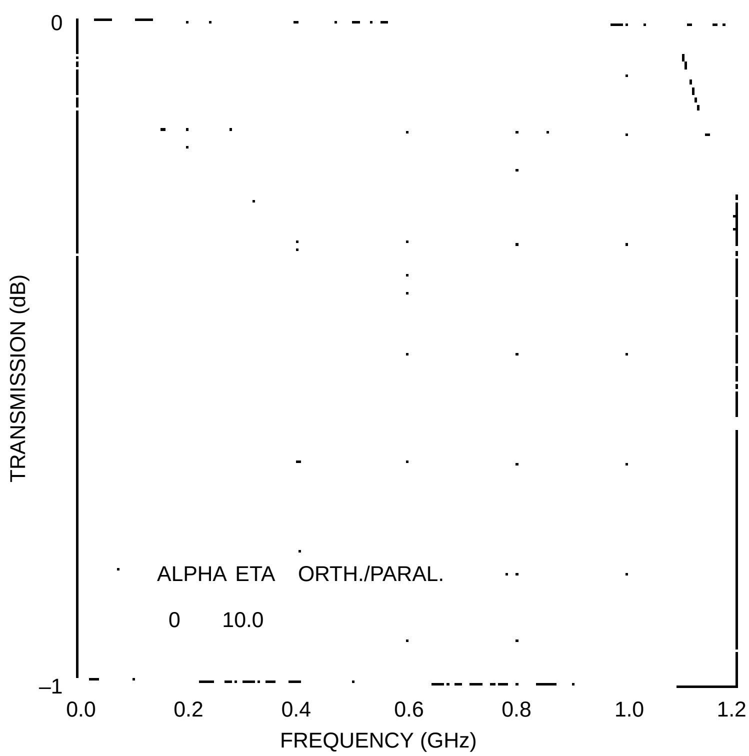


(c) element configuration for third FSS layer

Figure 6. Configurations for FSS elements.

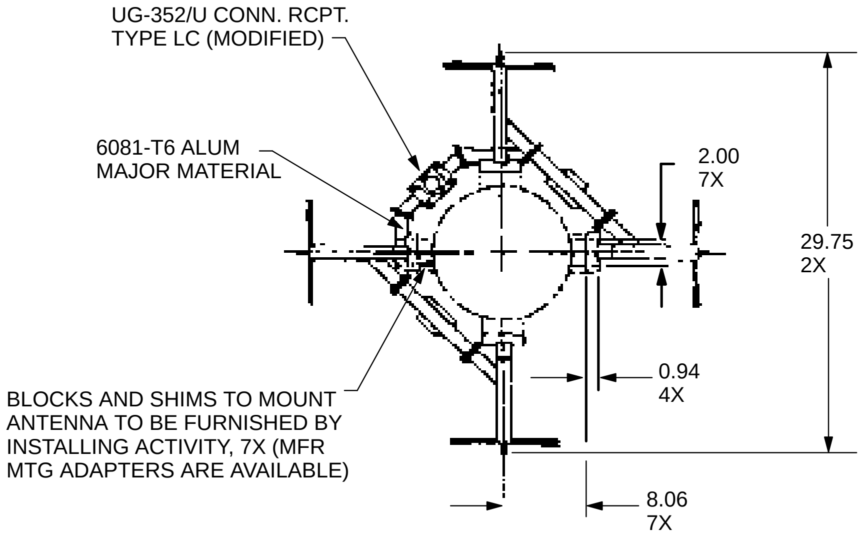


(a) transmission loss versus frequency

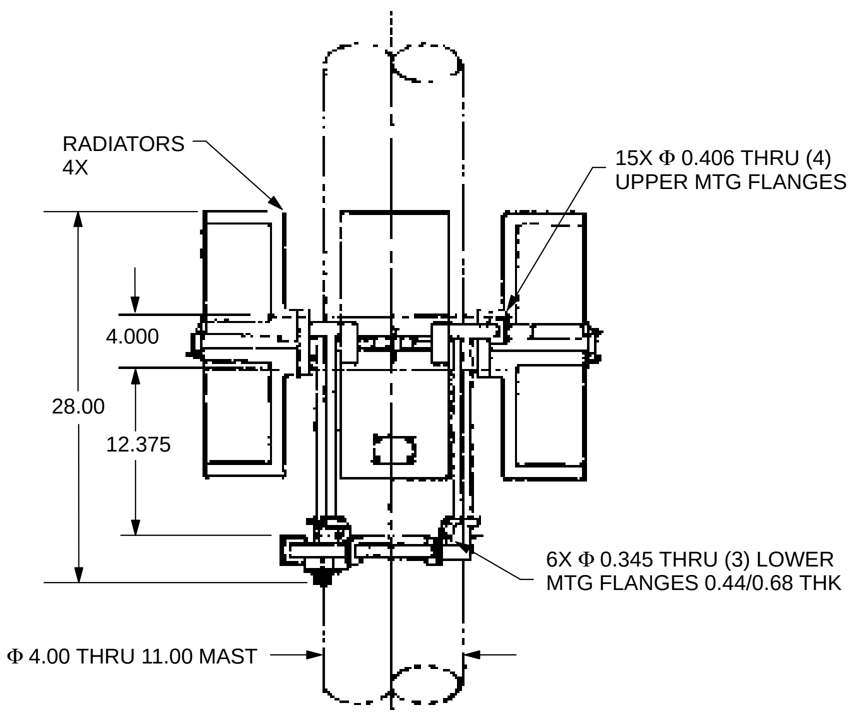


(b) in-band transmission loss in dB

Figure 7. Radome performance.



(a) top view



(b) side view

Note: All dimensions are in inches (UHF portion).

Figure 8. Proposed configuration for VHF/UHF antenna elements.

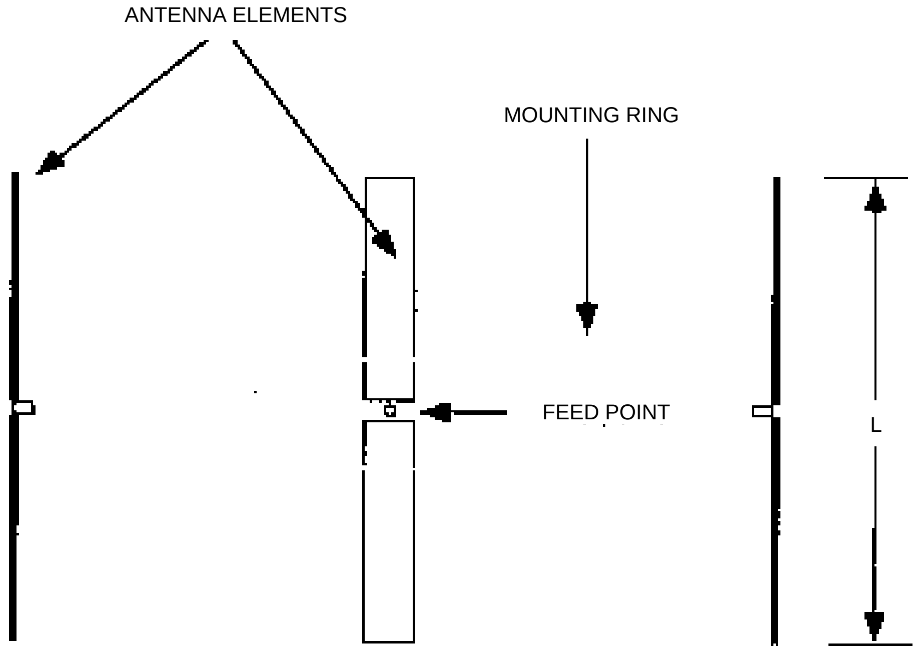


Figure 9. Proposed configuration for L-band antenna elements.

For the IFF array, an array of dipoles is proposed instead of a more conventional type. This configuration is proposed because of the less stringent bandwidth requirements for the L-band compared to the UHF and VHF bands. The array can be circular and built around the cable trunk to provide omnidirectional azimuthal coverage. The matching network can be built onto the cable trunk, providing the proper matching neccesary to obtain maximum efficiency. Figure 9 shows the configuration for the L-band radiators.

3.0 CONCLUSIONS AND RECOMMENDATIONS

A concept for an integrated stub mast antenna has been formulated. The new antenna system will have RCS signature-controlled capabilities. The radome uses FSS elements to provide a low in-band insertion loss with a high out-of-band rejection level. The design is also based on the availability of commercialized composite materials, such as E-glass, FR4, foam, and honeycomb. Calculated data show a transmission loss of about 0.4 dB at UHF and 0.17 dB at VHF frequency. A typical minimum out-of-band rejection level is about 20 dB, extending from 5 GHz to 18 GHz. The configuration for antenna radiators is built around the cable trunk with built-in matching impedance transformers. The radiators for UHF and VHF are the flat-type type of dipoles. A more conventional dipole is proposed for the L-band due to the less stringent bandwidth requirements. Future studies should examine the other remaining design issues, including attachment of the FSS radome onto the antenna framework, interface between the integrated stub mast and the top deck, thermal/IR treatments, and feeding network for both stub mast antenna and lights.

4.0 REFERENCES

1. Ho, T. Q., J. C. Logan, and C. A. Deneris, “An Experimental Bandpass Frequency Selective Surface Radome,” Naval Command, Control and Ocean Surveillance Center, Technical Document 2611, February 1994.

2. Henderson, L. W., “Introduction to PMM,” version 3.0, OSU ElectroScience Laboratory, Department of Electrical Engineering, May 1989, pp.9-24.

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13. ABSTRACT *(Maximum 200 words)*

This report describes a concept for designing radar cross section (RCS) signature-controlled communication antennas. The theory and design procedure for a frequency-selective surface (FSS) radome is discussed. Flat panel and conventional dipoles are used to realize the bandwidth requirements for VHF, UHF, and IFF bands. Design data are presented with recommendations for future studies.

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